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	Engineering and Design RESPONSIBILITY FOR HYDRAULIC STEEL STRUCTURES	
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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
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ER 1110-2-8157

Regulation
No. 1110-2-8157

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**Engineering and Design
RESPONSIBILITY FOR HYDRAULIC STEEL STRUCTURES**

1. Purpose.

This regulation defines engineering responsibilities for design of hydraulic steel structures, and for engineering inspection and evaluation during construction and operation of the project.

2. Applicability.

This regulation applies to all USACE commands having responsibility for Civil Works projects.

3. References.

- a. ER 1110-2-100, Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures.
- b. ER 1110-2-101, Reporting of Evidence of Distress of Civil Works Structures.
- c. ER 1110-2-112, Required Visits to Construction Sites by Design Personnel.
- d. ER 1110-2-1150, Engineering and Design for Civil Works Projects.
- e. ER 1110-2-1200, Plans and Specifications for Civil Works Projects.
- f. EM 1110-2-2105, Design of Hydraulic Steel Structures.
- g. American Association of State Highway & Transportation Officials (AASHTO) 1978. "Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members," Washington, DC 20001
- h. Federal Highway Administration (FHWA) 1986. Inspection of Fracture Critical Bridge

Members, Supplement to the Bridge Inspector's Training Manual. Report No. FHWA-IP-86-26.

4. Background.

a. Definition of Hydraulic Steel Structures. Hydraulic steel structures (HSS) are structures which control or regulate water and are typically part of a larger navigation, hydropower or flood control project. Typical HSS include lock gates, dam spillway gates, tainter valves, flood protection gates, stoplogs, bulkheads, and lifting beams used for installing other HSS. This regulation applies to all HSS being designed, fabricated, operated or inspected by the district with the exception of small size, low head standard manufacturer's designs. Many components of the operating machinery are designed and function integrally with the structural components of the HSS. To the extent possible, the provisions of this regulation shall also apply to such components.

b. There have been recent incidents of significant distress in HSS at Civil Works projects. In some cases the distress has been so severe as to warrant complete replacement of the structure (Ice Harbor Lock, lift gate, 1994, \$6 million) and, in at least one case, to cause collapse of a structure under hydrostatic load, nearly resulting in loss of life (Coffeerville Lock, maintenance stoplogs, 1994). Other lift gates have been replaced due to severe cracking (Melvin Price Lock and Upper Mississippi River Lock 27), miter gates have been investigated and repaired due to cracking (Markland Lock), and there has been a failure of a tainter gate (Folsom Dam, Bureau of Reclamation). There have also been a number of failures of operating equipment, including wire rope, machinery anchorage and hydraulic gate-operating systems.

c. In many cases, the primary form of distress has been fatigue damage and/or fracture. The most

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common causes of fatigue cracking have been a lack of proper detailing during design, poor weld quality during fabrication and poor detailing and execution of repairs. Recent inspections by districts have indicated that a significant number of stoplogs and bulkheads had deficient welds which required repairs. Many of these deficiencies were the result of ineffective quality control during the original fabrication welding of the structures. Corrosion is also a common form of distress, but is often more readily apparent before resulting in failure than fatigue cracking or incipient fracture.

d. The project impacts of distress or failure are significant. Failure of gate operating systems can render lock and flow control gates inoperable, causing delays to river traffic or possible overtopping of the project. Structural failure of a lock gate could severely impede or stop river traffic. Catastrophic failure of a spillway gate, dewatering bulkhead or a lock gate could cause uncontrolled release and/or loss of pool resulting in loss of life. Other forms of distress such as fatigue cracking can necessitate frequent inspections or a lengthy repair which, in turn, could delay river traffic. The repair of damaged or failed structures will divert maintenance funds from other high-priority projects.

5. Policy.

a. Responsibility. The district Chief of Engineering Division is responsible for ensuring that new HSS are adequately designed, and that appropriate quality assurance and engineering support are provided for fabrication, erection, operation, inspection and maintenance of each new and existing HSS. For each HSS, a qualified engineer should be designated as being primarily responsible for supervising or performing the actions defined in subsequent paragraphs. Funding and scheduling for these actions should be accomplished through normal budgetary procedures.

b. Qualifications. The designated engineer shall have an academic background or subsequent continuing education that includes structural steel design, welding, fatigue and fracture analysis, and fabrication methods. The engineer shall also have at least three years experience in the design, inspection

and evaluation of HSS. If possible, the designated engineer should be the person with direct oversight of the design or evaluation, or responsibility for technical review if the design or evaluation is performed by an A-E.

c. Required Actions.

(1) Design. The engineer shall ensure that the HSS is designed per USACE criteria, that it is safe, and that it will be able to reliably perform its intended function. This means that the HSS must be properly analyzed and detailed, and that project specifications are technically adequate and consistent with the design intent. Required actions during the design phase are more fully described in paragraph 6 of this regulation.

(2) Construction. To help ensure the design intent is properly executed, the engineer shall coordinate with Construction Division to communicate technical requirements for fabrication and erection, and to review specified contractor submittals. Required actions during the construction phase are more fully described in paragraph 7.

(3) Operation. For USACE operated projects, fracture critical members must be inspected every five years, and some require a special initial inspection. All HSS must be inspected every 25 years, even if this requires dewatering. The engineer shall coordinate with Operations Division to provide necessary inspections and evaluations, and technical support for maintenance and repairs. Required actions during the operation phase are more fully described in paragraph 8. Where project operation is the responsibility of the local sponsor, the sponsor is responsible for adequate inspections. The Operations and Maintenance Manual should identify the sponsor's inspection responsibilities.

6. Design Phase.

a. Design Criteria. Design of HSS shall be in accordance with EM 1110-2-2105. The engineer shall ensure that the following types of design requirements are satisfied: strength, serviceability, fatigue and fracture, corrosion and wear. Sufficient analyses must be performed to ensure a safe, functional and

reliable design. This includes sizing of members, connection detailing and compatibility with adjacent features. Analyses shall be performed and checked by separate engineers.

b. **Fracture and Fatigue Control.** Fracture and fatigue control requirements are defined in EM 1110-2-2105. The engineer shall ensure that all cyclically loaded components have been designed to meet the fatigue design requirements. This includes all attachments and connections to cyclically loaded members. The engineer shall also ensure, as required by the EM, that all fracture critical members (FCM) have been specified to meet minimum material toughness criteria and additional fabrication and inspection requirements in accordance with the AASHTO Fracture Control Plan (AASHTO 1978). FCM are defined herein as "members and their associated connections subjected to tensile stresses, whose failure would cause the structure to collapse". The definition of FCM applies to members whose primary loading is axial as well as components of members that are in tension, such as the tension flange of a flexural member. Fatigue and fracture control are critically affected by the quality of fabrication and construction procedures. Therefore, engineering requirements for fabrication and construction procedures should be provided to construction personnel as outlined in paragraph 7.

c. **Plans and Specifications.** Plans and specifications (P&S) shall be prepared in accordance with ER 1110-2-1200. The P&S are the final products of all the preceding design and review efforts. They define legal requirements for the contractor and are the basis for construction bids. The engineer shall ensure that the P&S include all necessary requirements governing fabrication and erection of the HSS. Guide specifications may be used as a tool for preparing project specifications, however, the engineer must ensure that guide specifications are properly adapted to reflect specific project requirements. The following information shall be included in the P&S.

(1) Most connections (especially those for FCM, other highly stressed critical members, and members subject to fatigue) should be detailed by the designer, not the steel fabricator. For building construction,

fabricators often detail standard shear connections and other common types of joints. However, connections on HSS are usually more complex, are often fully welded, and are used to transmit a combination of forces. When connections are to be designed by the fabricator, all required information shall be provided in the P&S, including design forces for the connection. Design forces should be clearly identified as factored or unfactored. The engineer must review any connections designed by the fabricator, to ensure compliance with the design requirements.

(2) All FCM shall be clearly identified on the drawings, and the material toughness requirements for these members shall be defined in the specifications.

(3) Requirements for weld inspections shall be clearly defined in the P&S. All welds should require at least a visual inspection. The engineer shall also require non-destructive testing (NDT) of all welds on FCM using an appropriate technique, such as radiographic, ultrasonic, dye penetrant, etc. The drawings or specifications should also identify other critical connections (in addition to FCM) which require NDT. The specifications should also require NDT of a sampling of other welds.

d. **Technical Review.** Independent technical review is a key element in design quality control plans. The engineer responsible for the HSS should ensure that an adequate review is performed, and that issues raised by the review are fully resolved.

e. **Certification.** The Chief of Engineering is required to certify the adequacy of certain design processes and products. For each HSS, the engineer must provide appropriate input for such certifications.

f. **Repairs and Modifications.** The design of repairs or modifications to existing HSS shall meet the requirements for new designs, as defined above.

g. **Operation and Maintenance Manual.** As a continuation of the design process, Engineering Division usually prepares a project Operation and Maintenance (O&M) Manual, though this may be done during the construction phase. The engineer should include information in the O&M manual identifying all FCM, and other highly stressed tension

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members, in each HSS. To control fatigue and fracture, the O&M manual should emphasize the importance of consulting with Engineering Division and using certified welders and qualified welding procedures when welding on these members. The manual should include recommendations for future inspection procedures and frequency for the FCM and other critical connections. Where HSS are turned over to local sponsors, the O&M manual must clearly identify recommended inspection methods and frequency.

7. Construction Phase.

a. General. The engineer should provide engineering support for the HSS during construction of the project. Areas of involvement include shop drawing and other construction submittal reviews, contract modifications, value engineering (VE) proposals, construction site visits, consultation with office and field construction personnel on interpreting the P&S, and on procedures to be used for fabrication and erection.

b. Engineering Considerations and Instructions for Field Personnel. As required by ER 1110-2-1150, Engineering Division should transmit a report to Construction Division, and to the Area/Resident Engineer, to aid them in supervision and inspection of the construction contract. A meeting among designers, district construction personnel and contractor personnel prior to construction is beneficial for identifying and discussing contract requirements and establishing a partnering relationship. As a minimum, the coverage of HSS in the report and meeting should include materials, welding procedures, quality control (QC) testing and quality assurance (QA) that are part of the fatigue design and fracture control plan; any special construction sequences that must be followed; critical tolerances that must be met; critical structural shop drawings that need review by design engineers; and contractor performed extensions-of-design that must be reviewed by design engineers. Submittals to be reviewed by the engineer should be so indicated on the Submittal Register. Also, as required by ER 1110-2-112, the schedule of field visits by design personnel should be included. This schedule should identify what structural steel details the engineer should observe during

construction, and at what stage of construction the visit should occur.

c. Design During Construction. Typically, during the construction phase, the only design analyses performed by the engineer are those required to resolve field problems. All design actions during construction are subject to the same technical review requirements as for new designs. The engineer should be involved in evaluating contract modifications to assure that both design criteria and construction concerns are satisfied.

d. Review of Submittals. The engineer must coordinate with Construction Division to be designated as the reviewer of the appropriate submittals on the Submittal Register. Any extension-of-design actions by the contractor should be reviewed by the engineer. Typical shop drawings that shall be reviewed include structural steel joint details completed or changed by the contractor, and items such as fabricated sluice gates that are designed by the contractor. The engineer should be involved in approving the location and details of structural steel joints not detailed on the contract plans because these may affect structural adequacy.

e. Contractor Designed Components. The engineer needs to specify design analysis submission requirements for any structural steel components designed by the contractor. The engineer shall review the design for these items to assure that they result in a structure that meets functional and technical requirements specified in the P&S. Some typical items include supplier designed sluice gates, mechanical equipment supports, etc.

f. Contractor Value Engineering Submissions. VE proposals for HSS that involve changes to the contract P&S shall be reviewed by the engineer. Review shall ensure that proposed changes result in a safe structure by complying with the original design criteria established for the project.

g. Final Inspection of Completed Construction. The engineer shall be a member of the engineering team that participates with construction personnel performing a final inspection before final acceptance of the project from the contractor.

h. **Permanent Records.** Records that document the materials and quality of construction are important for future evaluation and maintenance of the HSS. Engineering and Construction Divisions shall assemble a copy of items including mill certificates, weld inspection records, and details of contractor designed items, and shall forward them to the appropriate Project Field Office to be retained as permanent records along with the design documents, as-built drawings and specifications.

i. **Supply Contracts.** Some of the usual construction contract administration procedures are not applicable when a HSS is procured by a supply contract. For supply contracts, the engineer must coordinate with Contracting to ensure that appropriate requirements are included in the contract. The engineer must also coordinate with Construction to define applicable QA/QC requirements, and to determine appropriate USACE inspection actions.

8. Operation Phase.

a. **General.** It is essential that engineering and operations personnel maintain a close working relationship concerning any significant problems which occur during operation of the HSS. The engineer must coordinate with Operations Division to fund and perform scheduled periodic inspections or unscheduled special inspections.

b. **Modifications/Repairs.** All significant modifications and repairs to HSS and any modification or repair to a FCM shall be designed or reviewed by the engineer and shall conform to the applicable requirements of paragraph 6. Welded joints in FCM should be repaired by eliminating the defective weld metal and rewelding the joint or reinforcing the joint with bolted cover plates. Execution of the repairs shall be subject to the applicable requirements of paragraph 7, whether the repair is performed by contractor or project personnel. Structural adequacy of the repaired joints will be verified by certified inspectors and the results will be included in the permanent project files.

c. **Inspection Methods.** The purpose of the engineering inspection of HSS is primarily to evaluate

structural adequacy, rather than the general maintenance condition. The focus of the inspection should be on the critical structural members and connections most susceptible to various forms of degradation, particularly cracking. Detection of cracks requires a close visual inspection, and possibly non-destructive testing (NDT), of critical members and joints. Close visual inspection involves physical contact with the member, and may require cleaning of areas with potential cracks. Inspection of welded connections of FCM in existing HSS should be accomplished by an appropriate NDT method whenever possible. Use of NDT inspection should also be considered for other critical elements when their failure would result in large economic losses. When visual inspection identifies cracks on critical members, they should then be inspected by NDT to determine the extent of the discontinuity.

d. **Inspection Plan.** An inspection plan should be developed for each HSS. The plan should identify the members, joints, connections, and welds that are to be inspected, the type of inspection each is to receive, and the evaluation methods. The plan must identify any equipment needed to provide safe access to the members. The extent of inspection will depend upon member importance, the type of HSS and its function, and on the purpose of the inspection. Drawings, design analyses, inspection reports, and O&M records are useful in developing the inspection plan. Those that require NDT will cost more and take longer than those requiring only a close visual inspection. The plan should prioritize inspection of members, including adjacent joints, in the following order:

- (1) FCMs with life safety impacts
- (2) Other FCMs
- (3) Primary tension members or tension flanges
- (4) Primary compression members or compression flanges
- (5) Secondary structural members
- (6) Non-structural items

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e. Types of Inspections.

(1) Operations Inspections. Project personnel frequently inspect all project features. The engineer should coordinate with Operations Division whenever these inspections reveal any significant distress. Reports from these inspections are useful in developing plans for the engineering inspections.

(2) Routine Inspections. ER 1110-2-100 requires periodic inspection, by Engineering Division personnel, of completed Civil Works structures. Since that regulation contains only general requirements applicable to all project features, specific requirements for inspection of HSS are described herein. A periodic inspection is a regularly-scheduled inspection consisting of sufficient observations and measurements to determine the physical and functional condition of the HSS, to note any changes from previously recorded conditions, to identify any developing problems, and to ensure that the structure continues to satisfy present service requirements. For HSS whose failure could result in loss of life, the critical components should be examined during each inspection.

(3) Initial FCM Inspection. Special inspections are required for each FCM on all existing HSS, where failure of the FCM would result in probable loss of life. The inspection shall include NDT of all welded connections on the FCM. These requirements are waived if detailed inspection records are available from the original fabrication or from previous periodic inspections. The purpose of this inspection is to ensure that the FCM and its connections were properly fabricated so there are no defects which could result in failure before the next periodic inspection. An analytical determination of load capacity and estimated life shall be made before an HSS with known defects is returned to service.

(4) Damage Inspections. A special inspection may be required to assess structural damage resulting from natural causes, accidents, or normal wear. It may follow a specific damaging event, or be a more detailed inspection following identification of distress during a periodic inspection. The scope of inspection must be sufficient to determine whether to continue operation of the HSS, the need for emergency repairs

to ensure safety, and to assess the level of effort necessary for temporary or permanent repairs. The amount of effort expended on this type of inspection will vary significantly depending upon the extent of the damage and urgency of continued operation. If major damage has occurred, inspectors must evaluate fractured members and section loss and make measurements for misalignment of members. It may be necessary to make on-site analyses and decisions to establish emergency operation procedures. A refined analysis may be necessary to establish or adjust interim operational procedures. When documenting damage inspections, the engineer should be aware of any potential for litigation.

f. Inspection Frequency. HSS may be inspected at the same time as other project features during a periodic inspection, or may be inspected at times which will maximize the effectiveness or efficiency of the inspection. The engineer must ensure that, as a minimum, each HSS is inspected according to the following schedules. To ensure that these schedules are followed, it will be necessary to mark and record a permanent identifying number on each HSS. This will permit identification when HSS are moved or interchanged.

(1) The initial FCM inspection of stoplogs and bulkheads used for dewatering, and for related lifting beams, shall be completed prior to their next use. Initial FCM inspections of other HSS must be completed by 31 December 1998. Subsequently, all FCM must be inspected every five years. When dewatering is required to perform these subsequent inspections, the engineer shall decide whether such inspections are required. This decision will be based on an evaluation of the previous condition of the FCM, the number and magnitude of load cycles since the last inspection, consequences of potential failure, and the difficulty and cost associated with dewatering.

(2) As part of the periodic inspection program, each HSS should be dewatered and thoroughly inspected every 25 years. More frequent HSS inspections may be required based upon paint system life expectancy, operational problems (vibration, noise, deflections, damage, etc.), and past performance of similar structures.

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(3) When several of the same type of HSS exist at a project, at least one of each type of HSS must be inspected as part of each periodic inspection. A different HSS should be selected for each inspection. This selection should be based on the time since the HSS was last inspected, and which HSS has experienced more loading cycles or more severe operating conditions. If the HSS cannot be dewatered for this inspection, the portion above water should be inspected.

(4) When a HSS cannot be dewatered for a normally scheduled inspection, it should be inspected whenever it is dewatered prior or subsequent to the scheduled inspection. This may occur when Operations Division schedules painting or repairs. The engineer must coordinate with Operations Division to arrange for such inspections.

(5) When a problem is discovered during an inspection, similar HSS should also be inspected even though they may not have been scheduled for an inspection.

g. Inspection Evaluation. Whenever distress of a HSS is noted during inspection, the engineer should thoroughly evaluate the adequacy of the structure to ensure safety and reliable project function. ER 1110-2-101 defines procedures to be followed when reporting evidence of distress.

h. Inspection Report. For each HSS inspection, other than operations inspections, a report should be prepared and included in the next project Periodic Inspection Report. The report should identify the structure, inspection date, results of inspection and evaluation, and recommendations. Reports should also describe all modifications and repairs, including weld inspection results, that have been made on the structure since the last engineering inspection. All NDT reports, photographs, and radiographs should be included in the inspection report, so that they may be compared with subsequent NDT reports. The report should include a certification, by the Chief of Engineering, that the inspection and evaluation was adequately performed by a qualified engineer. All inspection reports, records, and photographs will be maintained throughout the life of the HSS.

FOR THE COMMANDER:



OTIS WILLIAMS

Colonel, Corps of Engineers
Chief of Staff